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Abstract

We examined a model of the impact of a 3D desktop virtual reality environment on the learner characteristics (i.e. perceptual and psychological variables) that can enhance chemistry-related learning achievements in an introductory college chemistry class. The relationships between the 3D virtual reality features and the chemistry learning test as it relates to the selected perceptual (spatial orientation and usability) and psychological (self-efficacy and presence) variables were analyzed using the structural equation modeling approach. The results supported all the hypothesized relationships except one. Usability strongly mediated the relationship between 3D virtual reality features, spatial orientation, self-efficacy, and presence. Spatial orientation and self-efficacy had statistically significant, positive impact on the chemistry learning test. The results indicate that 3D virtual reality-based instruction is effective for enhancing students' chemistry achievement. Overall, this study contributed a research model that can help increase the effectiveness of desktop virtual reality environments for enhancing spatial ability and science achievement. Moreover, this study provides insight to science educators, instructional designers, and multimedia developers who are interested in designing science-based instruction using instructional design principles.

Key words: Second Life®, science/chemistry achievement, spatial ability, structural equation modeling, self-efficacy.

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1. Introduction

1.1 Learner characteristics and science achievement

Many concepts in the field of science require the understanding of spatial relationships. For example, in the field of medicine, understanding human anatomy in a 3D perspective plays a critical role during surgery. In the field of chemistry, a chemist must visualize the arrangement of atoms in a 3D space to know the shape of molecules. Recent reviews indicate that lack of spatial instruction makes learning of a concept highly challenging for the students, which in turn, adversely affects their achievements (Gilbert & Boutler, 2000; Harle & Towns, 2011). Students' difficulty in learning chemistry concepts may also influence their self-efficacy (House, 1993; Oliver & Simpson, 1988). Research reports suggest that self-efficacy acts as a catalyst in expediting the learning process (Lapan, Shaughnessy & Boggs, 1996; Tymms, 1997). Therefore, embedding spatial training in chemistry instruction using desktop 3D virtual reality environments' features can play a mediating role in enhancing students' chemistry achievement.

1.2 The 3D virtual reality features and science achievement

Desktop virtual reality can be defined as a simulation of a real environment or a 3D representation of an abstract concept created using computer technology, wherein users have the ability to interact with the virtual environment in real time using various control devices (Ausburn & Ausburn, 2004; Slater & Usoh, 1994). Users can explore desktop virtual reality applications on a high resolution conventional PC using keys or a mouse for navigation (Simpson, 2003; WhatIs, 2005). With the massive increase in the computer processing power and rapid proliferation of the World Wide Web, many 3D virtual reality technologies are now commonly available (Dickey, 2005; McLellan, 2004). Educators are finding this technology

useful to teach many academic concepts (Buchanan, 2003). Studies conducted to test the effectiveness of the 3D virtual reality learning environment have shown positive results. Therefore, researchers are attesting to the learning effectiveness of this environment in fields such as medicine (Riva 2003), occupational and technical education (Ausburn & Ausburn, 2008), and engineering (Sorby, 2009).

One of the most vital and promising affordances of the virtual reality technologies is to provide spatial instruction. According to Moore (1995) "….by teaching the students to think in 3D using visualization techniques, their spatial cognition can be enhanced" (p. 5). Similarly, Hedberg and Alexander (1994) who emphasized the benefit of using 3D virtual reality environment stated, "As ideas are represented in a three dimensional world, three dimensional thinking can be enhanced, and the mental transformation of information from two to three dimensions can be facilitated" (p. 216). Dalgarno, Hedberg, and Harper (2002) propose that "If 3D environment is a metaphorical representation of abstract ideas, it may be that by developing an integrated database of two dimensional views of a three dimensional model of the concepts, we are better able to make sense of the concepts than through other instructional approaches" (p. 8). As espoused by these scholars, one of the critical features of 3D virtual reality environments is the ability to visually depict and interact with spatial representations of abstract concepts. Therefore, this feature of 3D virtual environments can be useful in providing instruction for developing spatial ability.

1.3 Need for conducting sophisticated statistical analysis

Many studies conducted to examine the effectiveness of virtual reality technologies in the field of chemistry have found positive effects (Barnea & Dori, 1999; Pribyl & Bodner, 1987; Urhane, Nick, & Schanze, 2009). However, researchers must focus attention on analyzing the

role of the mediating variables between the effects of 3D virtual reality technologies based instruction and chemistry learning. According to Waller, Hunt, and Knapp (1998), 3D virtual reality technology researchers should consider exploring perceptual and psychological variables that influence learning. Understanding the role of mediator variables can guide instructional designers, as they create learning tasks in response to the instructional need appropriately, utilizing virtual reality features. Lee, Wong, and Fung (2010) addressed this issue by developing a model of high school, biology students' learning processes and testing it using structural equation modeling (SEM). Lee et al.'s study represents an important advancement in the field of virtual reality technology, but more research of this type is needed. Therefore, in this paper, we propose a model that will examine the underlying perceptual and psychological variables involved during 3D virtual reality based instruction for learning chemistry and evaluate the model for an introductory college chemistry class using SEM analyses.

Many researchers have studied the impact of virtual reality technologies in chemical education because it is believed that students can form appropriate mental models of a concept by visualizing and interacting with the representation of the phenomenon (Antonoglou, Charistos, & Sigalas, 2011; Chiu & Wu, 2009; Phillips, Norris, & Macnab, 2010). A major contribution of this research is that it is the most comprehensive investigation to date of chemistry students' perceptual and psychological processes while interacting with a desktop 3D virtual reality learning environment, encompassing perceived usability of the features of the environment, learners' sense of presence in the environment, spatial orientation skills, and self-efficacy. In addition, an extensive search of the literature (Authors, 2011) did not reveal any studies of 3D virtual environments that used SEM analysis to study chemistry learning in 3D virtual reality environments. The understanding of the perceptual and psychological processes

provided by a theoretical model such as the one proposed here may help to guide the design and development of 3D learning environments and the effectiveness of employing them in instruction.

2. Theoretical framework

The general model of virtual reality proposed by Salzman, Dede, Loftin, and Chen (1999), which highlights the importance of 3D virtual reality features, concept taught, and learners' characteristics (i.e., learning and interaction experience) for learning outcomes in a virtual environment, served as a starting point for the development of our model. Using Salzman et al.'s (1999) model, Lee, et al. (2010) developed a general model examining the underlying psychological processes of reflective thinking, cognitive benefits, motivation, active control, and presence in the 3D virtual reality based instruction for high school science students. They found that virtual reality features were significantly influential in impacting the learning outcomes via the psychological processes included in their model. Our model is focused on testing the impact of perceptual and psychological processes associated with the learning of science concepts that involve understanding spatial relationships. For this study, we proposed and tested the model presented in Figure 1, which represents hypothesized relationships (H1-H7) between 3D virtual reality learning environment features (representational fidelity and learner's interaction) and a chemistry learning test as mediated by selected perceptual (spatial orientation and usability) and psychological (self-efficacy and presence) variables. More description of each variable is provided below.

2.1 Description of 3D virtual reality features

Many researchers of 3D virtual reality technologies have identified distinctive characteristics of this environment (Hedberg & Alexander, 1994; Steuer, 1992; White-lock,

Brna, & Holland, 1996). We concur with Dalgarno and Lee (2010)'s conceptualization of 3D virtual reality features because they derived their model based on a comprehensive synthesis of the literature available on this theme. According to them, there are two main features of 3D virtual reality environment, "representational fidelity" and "learners' interaction". Representational fidelity refers to the realistic display of the virtual environment that can be attained by physical characteristics of the environment such as rich graphics, smooth temporal changes, and consistent object behavior. For example, a photo-realistic display of a 3D molecule can create a perception of viewing a real molecule. Learners' interaction is the ability of users to influence the occurrences of events in the virtual environment by their actions. These would entail the capabilities of exploring, manipulating, rotating, and viewing objects from multiple perspectives. For example, a molecule can be rotated over a 360^{0} angle to view the different bond angles.

2.2 Perceptual and psychological variables

We delineated perceptual and psychological variables underlying the learning of the chemistry concept. One of the perceptual variables included in this model was spatial orientation, a component of spatial ability. It is important that college instructors pay special attention to students' misconceptions about chemistry concepts. One of the critical reasons why students find learning science concepts challenging is that they have preconceived, erroneous notions that have become entrenched and are difficult to eradicate. Many studies have found positive results when they addressed students' misconceptions using spatial training-based instruction (e.g., Trindade, Fiolhais, Almeida, 2002; Yezierski & Birk, 2006). Spatial orientation ability permits students to imagine simple or rigid transformations of an object by mentally rotating it in their minds (Ekstrom, French, & Harman, 1976; Lohman, 1988). For example, while studying bond

angles of molecular structures, students should be able to rotate a molecule dependent upon the number of atoms bonding together as well as the preferred perspective to view the bond angles.

In the 3D virtual reality environment employed in this study, students can view molecules with their bond angles from various perspectives using the zooming in and out feature. Moreover, they can also examine bond relationships between atoms within a molecule using different capabilities within the environment such as rotating and manipulating a molecule. This kind of learning task is similar to the process of mentally manipulating or transforming an object into another arrangement, which students are expected to perform to improve their chemistry understanding. It is likely that students with high levels of spatial ability can perform the necessary mental manipulations of molecular arrangement efficiently. However, researchers have found that typically students' lack this ability to view and transform 3D molecular arrangements mentally (Halpern & Collaer, 2005; Wu & Shah, 2004). Hoffler and Leutner (2011) conducted a meta-analysis of the effects of animations on students with low spatial ability and found that students performed better when they were instructed using animations than with static pictures. Therefore, by using the 3D virtual reality environments to manually manipulate and view 3D representations of molecular structures may enhance learners' ability to perform these transformations "in their minds".

Usability was another perceptual variable included in the model. Usability includes two subcomponents: perceived meaningfulness and perceived ease of use. Davis (1989) conceptualized the technology acceptance model after conducting an extensive survey in the field of information technology to understand how and when users will accept a new technology presented to them. According to Davis, several factors influence the decision of accepting a new technology but the most prominent and influential are perceived meaningfulness and perceived

ease of use. Similarly, Dalgarno and Lee (2010) state that the virtual reality technology in and by itself cannot afford learning. On the contrary, a designer has to employ these features to design a learning task, which can be perceived by the learners as meaningful and easy to conduct.

We considered including the variable of usability in our model because we designed the spatial instruction in a sophisticated 3D virtual environment of Second Life®. According to cognitive load theory (e.g., Schmidt-Weigand & Scheiter, 2011; Sweller, 1994; Van Merriënboer, & Sweller, 2005), when the presentation of instructional material is complex or inconsistent, it can produce extraneous cognitive load, reducing learners' capacity to adequately process learning tasks (i.e., germane cognitive load), and impeding the learning process (Kirschner, Kester, & Corbalan, 2011; Mayer & Moreno, 2003). Therefore, we were interested in exploring the dynamics of learners' perception of how easy it was to use Second Life® and how these perceptions were related to students' perceptual and psychological processes and learning outcomes. Often, researchers find that effectiveness of instruction disappears because learners' find the use of technology cumbersome. Understanding and seeking control over the technological features imposes an extraneous load on their cognitive resources. In such circumstances, merely redesigning the users' interface rather than the instruction can enhance learning gains. Therefore, it was essential for our study to assess the comfort level of the learners while using Second Life® for spatial instruction.

Self-efficacy was a psychological process included in our model. According to the social cognitive theory, self-efficacy influences students' academic achievement (Zimmerman, Bandura, & Martines-Pons, 1992). Self-efficacy can be defined as the beliefs a person has about his or her capabilities to successfully perform a particular behavior or task. The issue of self-efficacy in the students majoring in the science-related fields has been a big concern of

educators. Students' low self-efficacy has resulted into poor enrollment or attrition in the enrollment level after a few semesters (Chemers, Hu, & Garcia, 2001; Pajares, 1996). Moreover, development of self-efficacy in a computer mediated environment particularly with regards to virtual reality technologies is an under researched topic.

According to Bandura (1993), one of the key factors that influence learners' self-efficacy level is their perceived ability to interact and control the learning environment. The 3D virtual reality environment features of zooming in and out, rotating, and manipulating provides numerous opportunities for learners to acquire extensive control over their learning process. Learners can practice rotation of molecular structures to test their understanding of the chemistry concept. This opportunity of dynamically interacting with learning materials within the 3D virtual reality environment may prove influential in promoting learners' self-efficacy about learning chemistry concepts.

Presence was another psychological variable included in our model. Presence is defined "as the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998, pp. 225). In 3D virtual reality environments, users play an active role in dictating the occurrences of events utilizing various capabilities. For, example, in our spatial instruction, learners can break apart a molecule or bond atoms to form a molecule and thus enable them to examine its bond angles. This makes presence a process unique to the experience of the 3D virtual reality environment. According to some scholars, presence is an outcome of tangible 3D virtual reality features such as realistic display of the environment and interactivity (Whitelock, Brna, & Holland, 1996; Wenzel, Wightman, and Kistler, 1991); other scholars view it as a consolidation of sensation arising from the psychological processes of being involved and immersed in the environment (Regenbrecht &

Schubert, 2002; Witmer and Singer, 1998). However, more recently, with the availability of desktop based virtual reality technologies, presence has generated renewed interest among researchers. Currently, there is a debate on whether a desktop-based virtual reality environment, being a less sophisticated form of the high end 3D virtual reality technologies, is capable of creating a sense of presence (Nunez, 2004).

The purpose of this study was to examine the impact of 3D virtual reality features on chemistry learning outcomes in relation to the underlying selected perceptual (spatial orientation and usability) and psychological (self-efficacy and presence) variables. Delineating the impact of these constructs in conjunction with each other will provide insight in designing learning tasks involving spatial training. The results of this study will better inform science educators, instructional designers, and multimedia developers to optimize 3D virtual reality features for delivering science-based spatial instruction.

2.3 Testing the model

Figure 1 depicts the hypothesized latent factor mediation model and the paths to be tested using structural equation modeling analysis. The independent latent factor variable includes the 3D virtual reality features that are hypothesized to have a positive and direct relationship with the chemistry learning outcomes. The latent factor of 3D virtual reality features explains the observed variables of: representational fidelity and learners' interaction. Usability is another latent factor model factor that explains the observed variables of: perceived ease of use and perceived meaningfulness. Usability mediates the relationship between 3D virtual reality features, spatial orientation, self-efficacy, and presence. Spatial orientation, self-efficacy, and presence are observed variables hypothesized to have positive and direct relationships with the

outcome variable, students' achievement on the chemistry learning test. We tested the following hypotheses to assess the fit of the hypothesized model.

Hypotheses for testing direct relationships

H1: The 3D virtual reality features are positively and significantly related to usability.

H2: Usability is positively and significantly related to spatial orientation.

H3: Usability is positively and significantly related to self-efficacy.

H4: Usability is positively and significantly related to presence.

H5: Spatial orientation is positively and significantly related to the chemistry learning test.

H6: Self-efficacy is positively and significantly related to the chemistry learning test.

H7: Presence is positively and significantly related to the chemistry learning test.

Hypotheses for testing indirect relationships

H_{01}: Usability will mediate the relationship between the 3D virtual reality features and spatial orientation.

H_{02}: Usability will mediate the relationship between the 3D virtual reality features and self-efficacy.

H_{03}: Usability will mediate the relationship between the 3D virtual reality features and presence.

3. Method

The data presented here were collected as part of a quasi-experimental study evaluating the effects of the 3D virtual environment treatment described in this paper. Only the data from the group that received instruction using Second Life® were relevant for the analyses reported in this study.

3.1Participants

This study's participants were 238 undergraduates enrolled in the morning section of Chemistry 101 course at a large southern university in the United States of America during the spring 2011 semester. Of these 238 students, 2 chose not to participate in the study and another 8 dropped the class. Further, 24 students were dropped from the study because they completed the set of tasks out of order. The final sample consisted of 204 participants of whom 67% were female and 33% were male. Most of the participants' (92%) age ranged between 18-21 years. The weighted mean age of the students was 19.75 years and the weighted standard deviation was 0.09. They were mostly Caucasians (72%) or Hispanics (17%). More descriptive statistics can be found in Table 1. Students who were not included in the study did not differ from students who were included on the demographic variables.

3.2 Measures

The measures in this study were the chemistry learning test, the Purdue Visualization of Rotations Test (PVRT), and a self-report measure consisting of items on six variables. The six variables were representational fidelity, learners' interaction, perceived ease of use and meaningfulness, self-efficacy, and presence. Participants completed all three measures using the online Qualtrics survey tool.

3.2.1Test of chemistry learning

We selected the VSEPR (Valence-shell Electron Pair Repulsion) theory as a measure of chemistry learning because it is one of the most fundamental, abstract, and spatially demanding concepts in undergraduate chemistry courses, where students are expected to view molecules in a 3D space (Sorby, Charlesworth, & Drummer, 2006). Students draw a basic Lewis electron dot diagram to depict bonding and non-bonding electrons in a chemical species, which they then apply to determine its three dimensional shape. The instructor of the Chem101 course who has

taught this class for the past 27 years developed a multiple choice test on VSEPR theory consisting of 12 questions on molecular angles, molecular geometry, and species identifications. Participants scored one point for every question answered correctly and zero for an incorrect answer. Three chemistry professors reviewed this test to ensure its content validity. A pilot study of this test was conducted with 53 students who took Chem102 from the same instructor in the fall of 2010. After conducting item analysis, all the questions demonstrated an acceptable discrimination index, except one. Therefore, that question was deleted yielding an 11 item test. The item difficulty index for the 11 questions ranged between 0.20 - 0.81 which is of moderate difficulty level. The reliability coefficient alpha for pilot test score was 0.87, which is higher than the acceptable level recommended for learning achievement tests (Reynolds, Livingston, & Wilson, 2009).

3.2.2 Purdue Visualization of Rotations Test (PVRT)

This 20 question test developed by Bodner and Guay (1997) is a widely used measure of spatial orientation in the field of chemistry. Figure 2 is a sample item from the PVRT. PVRT items are analogy problems in which students are asked to perform the rotation that is shown at the top of the item, choosing from the five options shown at the bottom. Thus in the problem shown in Figure 2, option D is the correct answer. Each question in this test consists of a 3D object, participants are asked to select the correct rotated version of the object from the five alternatives provided. Participants are allotted ten minutes to complete all the 20 questions. Participants scored one point for every question answered correctly and zero for an incorrect answer. This test has consistently demonstrated a good reliability (KR-20) index ranging from 0.78 – 0.80 in a variety of research contexts.

3.2.3 Self-report measure

The self-report measure consisted of 41 items adapted from four different instruments measuring six variables of this study: representational fidelity (4 items), learners' interaction (3 items), perceived ease of use (8 items), perceived meaningfulness (10 items), self-efficacy (15 items), and presence (1 item). All the measures were adapted from previously validated instruments (See Appendix A) except for the measures of self-efficacy and presence because instruments available to measure these variables are very few. The instrument developed by Witt-Rose (2004) was considered the most comprehensive and appropriate to measure learners' self-efficacy level in the context of this study. We used the most popular and commonly used presence measure designed by Slater and Usoh (1994). Items for all the above measures were based on the Likert scale with strongly disagree (1) to strongly agree (5), except for the measures of 3D virtual reality features, perceived ease of use, and perceived meaningfulness which were originally based on the Likert scale from not at all (1) to very much (7). Thus measurement scale of these instruments' items was reduced to 5, strongly disagree (1) to strongly agree (5) to maintain consistency with the other instruments used in this study. The only other modification made to the instruments was to reflect the context of the study. For example, one of the questions in the original self-efficacy instrument was "I am confident I can understand the material taught in anatomy and physiology (A&P)" was revised to "I am confident I can understand the material taught about VSEPR theory". More details for each measure are provided in Appendix A.

3.3 Instructional software

Second Life®, an innovative 3-D technology, launched by Linden Labs in 2003 was used to provide spatial instruction to this study's participants. This internet-based immersive virtual environment allows its users, who are called residents, to interact within this environment by creating their digital self-representation, called an "avatar" (Second Life.com). Second Life®

also has the ability to build 3D virtual objects (molecules in this instance). Other interactive features include the ability to interact with the object by zooming in and out, rotating the object, and programming the objects to behave in a certain manner. Currently, there are two spaces in Second Life® that exhibit fundamental chemistry concepts: Drexel University's simulation on chemical solubility testing and Texas A&M University's Dr K's Chemistry Corner on molecular structures.

3.3.1 Texas A&M University's Dr K's Chemistry Corner

Dr. Wendy Keeney-Kennicutt from the Chemistry department has built a corner in Second Life® (http://slurl.com/secondlife/12thMan/213/239/26, February 8, 2012). Students were familiarized with the environment of Second Life® and its features, using seven introductory videos specifically developed for this study. Later students completed three assignments in Second Life® using the simulations called 1) Molecule Game 2) The Chemist as an Artist 3) The Tower of VSEPR Theory. Following is the detailed description of each simulation set up in Second Life® and three activities student's completed in Second Life®. Sample screen shorts are presented in Figure 3

3.3.2 The Molecule Game

This game was designed for students to see the molecules in a 3D space from multiple perspectives. Students' had to "rezz" (i.e., to make an object appear in the Second Life® environment) molecules at five different stations to complete this assignment. After rezzing the molecules students were prompted to answer questions about the molecule they rezzed. For example, one of the stations had an ethane molecule. When students' rezzed the ethane molecule a note popped saying   "How many hydrogen atoms does an ethane molecule have?" The students could view the ethane molecule, count the atoms, and rotate the molecule to view from

different perspective in order to answer that question. On selecting their response, students received feedback and other supportive information to proceed further. Finally, students emailed a picture of their avatar taken at any one of the five stations to the instructor as a requirement to obtain credit for activity completion.

3.3.3 Chemist as an Artist

This simulation was designed to further develop students' ability to see molecules in a 3-D perspective. The participants were given three molecules to manipulate in Second Life®.They could rotate the molecule and link or unlink the atoms to thoroughly explore a molecule. For each molecule, they were required to provide a photograph of themselves with two orientations of their molecule, and a 2D drawing of each orientation using solid lines, wedges, and dashed lines.

3.3.4 The Tower of VSEPR Theory

This simulation was designed to enhance students' understanding of an important concept in chemistry called the Valence-shell Electron Pair Repulsion (VSEPR) Theory . Students were required to rezz 11 different molecules to complete a VSEPR theory report.

3.4 Procedure

The study began in the fifth week of the spring semester 2011. The instructor informed the students of CHEM 101 morning section about the study as a special project to be conducted during the semester. Participants received a syllabus handout containing all the details of the project (i.e., description and requirement to complete the assignments and credit assigned for the completion of the project). Beginning from the fifth week of the semester, participants had four weeks to complete the assignment of the "Molecule Game" and the "Chemist as an Artist". During the ninth week, participants could begin working on the assignment of "The Tower of

VSEPR Theory", and they had three weeks to complete the two assignments in the specified order. Before students began the assignment of "The Tower of VSEPR Theory", they were instructed on this topic for three consecutive class periods by the instructor. In the 12th week participants took the PVRT Test, the chemistry learning test, and completed the self-report measure.

4. Results

The descriptive statistics of all the variables included in the model are presented in Table 3. The fit of the hypothesized model was assessed using the SEM approach. SEM is considered a highly reliable technique for model testing because 1) measurement errors can be controlled using a latent factor model and 2) goodness of fit indices can be obtained to assess the relationship between the variables (Kline, 2010). Data were analyzed using MPlus Version 6.11 (Muthe`n & Muthe`n, 1998-2007). The maximum likelihood method of estimation was employed. A two-step procedure was undertaken to test the hypotheses.

A three-step procedure was undertaken to test the hypotheses. We first examined whether the items we used to measure a construct did significantly relate/load on that construct. The relation between the items and the corresponding construct can be translated into a measurement model. We adopted confirmatory factor analysis (CFA) under the structural equation modeling (SEM) framework to examine the hypothesized measurement model for each construct. In testing the measurement models, we used scores obtained by each student on every item of the instrument. Once we had acceptable model fit indices and factor loadings for each construct (as presented in Table 2), we then created the composite score of the construct which was the sum score of the corresponding items of that construct. This approach, also known as the unit weighting approach (Kline, 2010), is commonly used for creating a composite score that "has the

advantage of simplicity and less susceptibility to sample-specific variation" (p.204). There are two reasons that led us to using composite scores instead of including the full measurement models for all the constructs in the hypothesized model: 1) the inclusion of the full measurement model in the hypothesized structural model would increase the model complexity (i.e., with more free parameters for estimation), which could result in potential convergence issue; 2) according to the recommended rule of thumb for sample size in structural equation modeling, 10:1 (i.e., 10 observations for every free parameter; Bentler, 1995; Jackson, 2003; Kline, 2010), the current sample size (N=204) was adequate to estimate the hypothesized model with composite scores given that it contained 19 free parameters (i.e., at least 19*10 = 190 students were needed to estimate this model based on the 10:1 rule of thumb, 204 were included in the analysis). The inclusion of the full measurement model would substantially increase the number of free parameters and based on the rule of thumb, our sample size would not be sufficient to estimate such a complex model. Given these reasons, we determined to use the composite scores in testing the hypothesized structural model. Testing indirect relationships between constructs has been used by researchers to understand the processes underlying the direct relationship among the constructs (e.g., Hughes & Kwok, 2006) and was deemed essential for the purpose of this study. All the hypothesized indirect relationships were examined using the Type=Indirect procedure in Mplus.

4.1 Measurement model

Each measurement model was assessed based on the model fit indices, standardized factor loadings, and reliability to confirm constructs validity. According to Hu and Bentler (1999), goodness-of-model must be determined based on combined evaluation of fit indices. They recommend that CFI (Comparison Fit Index) and TLI (Tucker Lewis Index) values closer

to 0.96 and SRMR (Standardized Root Mean Square Residual) values close to 0.10 are needed. Moreover, RMSEA and SRMR values of 0.05 or 0.06 are also acceptable. Hair, Black, Anderson, and Tatham (2006) recommended that non-significant chi-squared statistics (χ^2) value, in combination with CFI and TLI values of 0.95 and above, and RMSEA and SRMR values less than 0.06 are needed. In addition, Browne and Cudeck (1993) and Hair, Black, Anderson, and Tatham (2006), both suggest that RMSEA and SRMR values less than 0.08 and CFI and TLI values of 0.90 constitute an acceptable level of model fit. All the measurement models met the required standards of a good model fit (see Table 2) except for the measurement model for representational fidelity.

Following Kline's (2010) guideline, the convergent validity can be shown by whether the observed variables are significantly related to the corresponding construct. According to the results of the measurement models, all the observed variables were significantly loaded on the corresponding constructs. The range of the factor loadings for each construct was presented in Table 2. Hair, et al. (2006) recommends that the factor loadings should be 0.50 or higher and ideally should be 0.70 or higher. All the items loaded significantly on their latent factors ($p <$ 0.01) and most of the factors loadings ranged between 0.51 – 0.91 indicating an overall high construct validity of the factors. Reliability coefficients alpha was calculated for the score of each observed variable. Most of the reliability coefficients were above the generally acceptable level of 0.70. McDonald's Omegas also were calculated and are presented in the Table 2. Overall, the omegas were either equal to or larger than the alphas. For measurement with a single item (e.g., presence in the current study), it is not possible to calculate the reliability co-efficient. Therefore, according to Hair, et al. (2006), decisions regarding the reliability of a measure with

single item can be determined based on researcher's best judgment. Overall, it was assumed that each measurement model indicated an acceptable level of construct validity.

The discriminant validity was examined by fitting all the observed items to a single-factor model in which they were loaded on the same factor. The results showed that this single-factor model produced poor fit, χ^2 (2484) = 9500.27, p <.001; CFI = 0.36, while more than 40% of the factor loadings were not statistically significant. The poor fit of the single factor model could be viewed as an evidence of the discriminant validity of the constructs given that the observed variables and the corresponding constructs were not only conceptually but also statistically different from each other. Therefore, we proceeded to conduct the next step in the analysis, which was testing the structural model.

4.2 Structural model

Figure 3 shows the results of the hypothesized structural model. We limited our analysis to testing only the hypothesized model because we developed this model based on the literature review and theoretical underpinnings. The overall goodness of fit indicates an acceptable fit (CFI = 0.953, TLI = 0.931, RMSEA = 0.06, SRMR = 0.04). All the model estimates were statistically significant and in the hypothesized direction.

The hypotheses of direct relationships H1, H2, H3, H4, H5, and H6 were supported. The only hypothesis that was not supported in this model was H7. Overall the model explained 45% of the variance (R^2 = 0.45) in the chemistry learning test, 34 % variance (R^2 = 0.34) in the self-efficacy, 29% (R^2 = 0.29) in presence, and 3% (R^2 = 0.03) in the spatial orientation. The 3D virtual reality features strongly and positively influenced the usability (β = 0.956, p < 0.001). Usability was strongly related to 3D virtual reality features and spatial orientation (β = 0.166, p < 0.05), self-efficacy (β = 0.579, p < 0.001), and presence (β = 0.540, p < 0.001). The

perceptual variable of spatial orientation ($\beta = 0.344$, $p < 0.001$) and the psychological variable of self-efficacy ($\beta = 0.513$, $p < 0.001$) was strongly related to the chemistry learning test. The only relationship that was non-significant was between presence and the chemistry learning test ($\beta = 0.069$, $p = 0.367$). All the hypotheses of indirect relationships H_{01}, H_{02}, H_{03} were supported. Usability mediated the relationship between 3D virtual reality features and spatial orientation ($\beta_{\text{3D Virtual features} \rightarrow \text{Usability} \rightarrow \text{spatial orientation}} = 0.16$, $p < 0.05$), self-efficacy ($\beta_{\text{3D Virtual features} \rightarrow \text{Usability} \rightarrow \text{self-efficacy}} = 0.55$, $p < 0.001$), and presence ($\beta_{\text{3D Virtual features} \rightarrow \text{Usability} \rightarrow \text{presence}} = 0.52$, $p < 0.001$).

5. Discussion

This study explored the role of psychological and perceptual processes in the learning of chemistry concepts in a 3D virtual reality environment. A theoretical model was developed based on previous research and theory in the area and tested using structural equation modeling. The results supported the hypothesized meditational paths from 3D virtual reality features to the usability and from usability to spatial orientation, self-efficacy, and presence. This study also found statistically significant and positive relationships between spatial orientation and self-efficacy and students' performance on a chemistry learning test. However, the hypothesized relationship between presence and chemistry learning was not supported. This study's results support the model proposed by Salzman et al. (1999) that learners' characteristics and the interaction experience mediate the relationship between 3D virtual learning environment features and chemistry learning outcomes with the exception of presence variable.

Our study makes a significant contribution because it is the first to use structural equation modeling to explore mediational relationships among the constructs that influence chemistry learning in a 3D virtual reality environment. In addition, it is the first study to examine the role of self-efficacy. According to the Salzman et al. (1999) model, a gamut of factors play mediating

roles when an instruction is designed using 3D virtual reality features to enhance learning achievement. In order to test the theoretical stance proposed by the Salzman et al. (1999) it was essential to develop a more fully articulated model that could then be tested using a statistical technique that allows examination of multiple relationships between concepts. Our study tested a web of relationships between several factors that influence chemistry learning with spatial orientation as one of them.

5.1 The chemistry learning test

The hypotheses of direct positive relationships between chemistry learning and spatial orientation (H5) and self-efficacy (H6) were supported. Overall, our model could explain nearly 50% of the variance in the chemistry learning test. This indicates that our model incorporated important predictors of performance on the chemistry learning test. The fact that students struggle with the learning of chemistry concepts is very well known. Our results indicated that students' spatial orientation skills and their sense of self-efficacy were strong predictors of chemistry learning in the 3D virtual reality environment we developed. There can be other predictors of students' performance such as teacher quality, physical classroom conditions, and peer influence that can explain the other variances in students' chemistry performance.

5.2 Self-efficacy

Our findings supported the hypotheses of direct relationship between usability and self-efficacy for learning chemistry (H3) and an indirect relationship between 3D virtual reality features and self-efficacy for learning the material presented in the chemistry class as mediated by usability (H_{02}). Students' interactions with 3D virtual reality features were related to their self-efficacy levels, which, in turn, predicted their performance on the chemistry learning test. The 3D virtual reality environment provided a high level of learners' interaction in the

environment. This suggests that students' ability to explore, manipulate, and rotate representations of molecular structures in the Second Life® environment may be related to their self-efficacy for learning chemistry. According to Bandura (1993), one key factor that influences individuals' self-efficacy level is their perceived ability to control the environment. The 3D virtual reality environment provided a high level of learners' interaction in the environment. Qualitative research in which students are asked to reflect on how learning in the 3D virtual reality environment enhanced their self-efficacy level might provide further insights into the underlying psychological processes related to self-efficacy occurring during the 3D virtual reality-based instruction, as might expansion of the research to include meta-cognitive variables.

5.3 Spatial orientation

The hypotheses of a direct positive relationship between usability and spatial orientation (H2) and an indirect relationship between 3D virtual reality features and spatial orientation also were confirmed (H_{01}). Our model explained 3% of the variance in spatial orientation, indicating that 3D virtual reality features play a significant role in enhancing students' spatial orientation ability. According to Thompson (2006), even a small effect size for a critical outcome can be very important. Spatial ability plays an important role in chemistry achievement (Mohler, 2006; Newcombe, Mathason, & Terlecki, 2002), and in our model, spatial orientation explained 34% of the variance in students' performance on the chemistry learning test. This finding is consistent with the model suggested by Salzman et al. (1999) that learners' characteristics mediate the learning process. Similarly, Dalgarno and Harper (2003) through their study have also demonstrated that 3D virtual reality features can be leveraged to design learning tasks that involve students thinking in a 3D perspective.

5.4 Usability

The latent variable of usability was highly related to the variables of perceived meaningfulness and perceived ease of use. The latent variable of usability strongly mediated the relationship between the 3D virtual reality features and the variables of spatial orientation, self-efficacy, and presence. This finding suggests that the 3D virtual reality features can support the development of learners' spatial orientation ability, self-efficacy, and presence only when the learners' perceive the experience as meaningful and the system easy to use. This finding is consistent with the model proposed by Salzman et al. (1999) where learners' usability is another significant mediator in the learning process. This finding also resonates with the finding of other studies that have demonstrated the importance of considering task meaningfulness and ease to use computer interface (Davis, 1983).

5.5 Presence

The results confirmed the hypothesis of an indirect relationship between the 3D virtual reality features and presence as mediated by usability (H_{03}). This indicates that students who used the Second Life® environment to complete the learning activities perceived themselves as being in the environment. This finding is consistent with the finding of other studies (Hall, Wilfred, Hilgers, Leu, Walker, & Hortenstine, 2004; Winn, Windschitl, Fruland, & Lee, 2002) that 3D virtual reality features are capable of providing higher immersion levels.

On the other hand, the results did not support the hypothesis of a direct relationship between presence and the chemistry learning test (H7). This suggests that students' sense of presence was not related to their performance on the chemistry learning test. Currently, there are mixed results on the impact of presence on learning outcomes. For example, in a studies conducted by Lee et.al (2010) and Burgess (2010) there was a positive relationship between presence and learning outcomes, but Mania and Chalmers (2001) and Moreno and Mayer (2002)

did not find statistically significant differences on learning outcomes measures of students when presence was manipulated by providing instruction in either higher or lower immersion level.

There could be several explanations of why the students' sense of presence was not related to chemistry learning in the present study. First, presence is an outcome of interaction between people and technology, which is an important component of instructional media. According to the literature on media effects on learning outcomes, media in and of itself cannot improve learning (e.g., Clark, 1989). Media should be used to design learning tasks in a way that best promotes interaction and engagement with the learning materials (Dalgarno, & Lee, 2010; Kozma, 1994). On the contrary, technological features supports the design of learning tasks that engages the learners in spatial instruction which were then instrumental in enhancing learning outcomes on chemistry test. Cognitive load theory (e.g., Schmidt-Weigand & Scheiter, 2011; Sweller, 1994; Van Merriënboer, & Sweller, 2005) provides a second possible reason for the failure to find the hypothesized relationship between presence and chemistry learning. The extraneous cognitive load of navigating the Second Life® environment employed in this study may have been so complex that students did not have sufficient cognitive resources left to take full advantage of the activities provided. Thus, students could feel present in the environment without that presence translating into knowledge gains. Finally, it is possible that the presence measure used in this study did not optimally capture students' perceptions. Instruments to measure presence are limited and have received mixed reactions on their comprehensiveness (e.g., Usoh, Catena, Arman, & Slater, 2000; Witmer & Singer 1998; Slater, 2004).

6. Conclusions

This study supported the hypothesized model for how students interact with a 3D virtual reality environment, which consisted of perceived usability of the features of the environment,

sense of presence in the environment, spatial orientation skills, and self-efficacy provided a good account of students' performance on the chemistry test. However, all data were collected from students of Chem 101 course at the university where the research was conducted. Therefore, the results may not be generalizable to the other content or students at other academic institutions. More studies need to be conducted in different contexts to replicate and generalize this study's results.

In spite of these limitations, our study makes an important contribution to the literature because it is the most comprehensive multivariate analysis of psychological and perceptual processes involved in learning chemistry in a 3D virtual learning environment and the first to test a model of chemistry learning in 3D environments to employ SEM. This study's results seem highly promising in designing learning environments using 3D virtual reality technologies such as Second Life® to enhance student performance on the chemistry learning test. In addition, the findings have important implications for chemistry instructors. Many educators believe that VSEPR theory is fundamental, but also one of the most challenging concepts where students struggle to attain better understanding. Given the importance and complexity of VSEPR theory, the study results suggest an instructional strategy that chemistry educators can use to improve their students' chemistry achievements. Many 3D virtual reality environments such as Second Life® have features that can support the design of learning tasks that can enhance students' spatial ability and improve learning outcomes. Therefore, chemistry educators and other science educators would be well advised to embed spatial training into the curriculum when teaching concepts that involve three-dimensional thinking.

Understanding spatial relationships is imperative for improving performance on many other science-related concepts. Our model is highly applicable to all the science-related

instruction that involves understanding spatial relationships. The findings of this study inform us of the potential of a 3D virtual reality environment like Second Life's to enhance undergraduate student performance on VSEPR theory. In addition, this model could be applied to design instruction to science-related topic that involves imparting spatial instruction. It should be noted, however, that direct experimental tests of these implications are needed.

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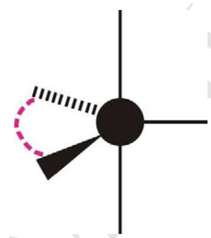
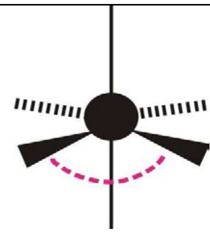
Appendix A

Itemized description of each instruments.

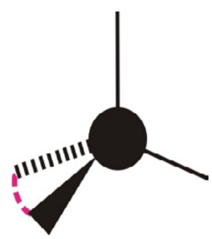
Variables	Items	Source
Chemistry Learning Test	1. A typical 3-dimensional representation of a molecule in 2-dimensional space uses wedges for bonds coming toward the viewer, dotted lines for bonds going away from the viewer and lines for bonds in the plane of the paper. What is the bond angle (rounded to the nearest whole number) expressed by the red dotted line in this molecule?  a) 30^0 b) 45^0 c) 60^0 d) 90^0 e) 109^0 f) 120^0 g) 150^0 h) 180^0 Correct Response: 120^0 2. A typical 3-dimensional representation of a molecule in 2-dimensional space uses wedges for bonds coming toward the viewer, dotted lines for bonds going away from the viewer and lines for bonds in the plane of the paper. What is the bond angle (rounded to the nearest whole number 0 expressed by the red dotted line in this molecule?	Self-developed



a) 30^0 b) 45^0 c) 60^0 d) 90^0 e) 109^0 f) 120^0 g) 150^0 h) 180^0

Correct Response: 90^0

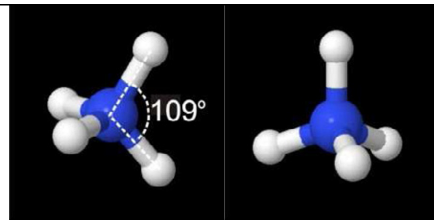
3. A typical 3-dimensional representation of a molecule in 2-dimensional space uses wedges for bonds coming toward the viewer, dotted lines for bonds going away from the viewer and lines for bonds in the plane of the paper. What is the bond angle (rounded to the nearest whole number) expressed by the red dotted line in this molecule?



a) 30^0 b) 45^0 c) 60^0 d) 90^0 e) 109^0 f) 120^0 g) 150^0 h) 180^0

Correct Response: 109^0

4.

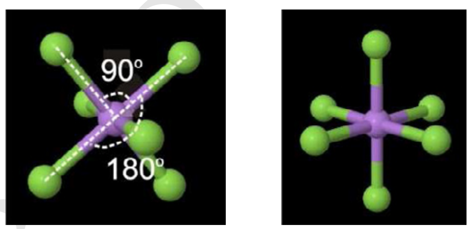


You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: tetrahedral

5.

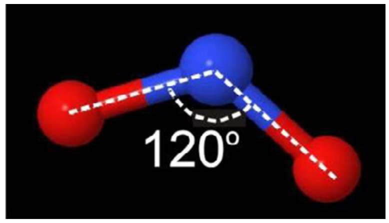


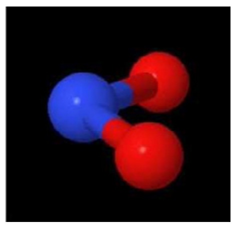
You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: octahedral

6.

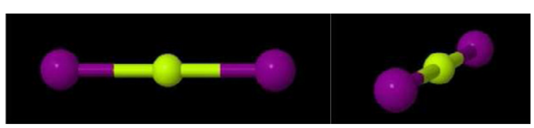




You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: bent or angular

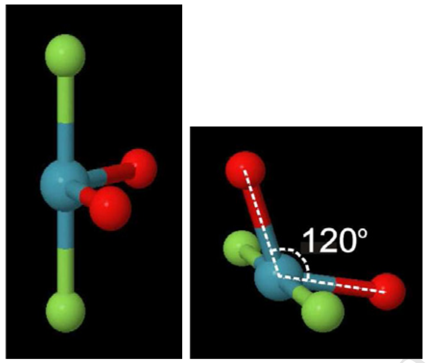
7. 

You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

a)bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e)

linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

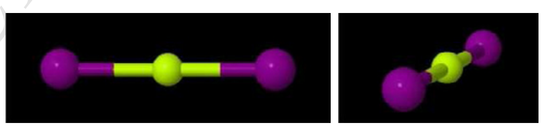
Correct Response: linear

8. 

You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

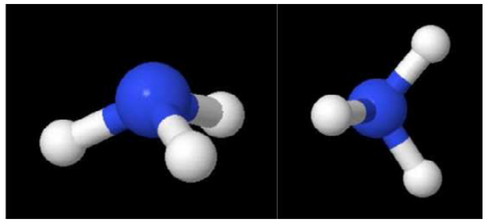
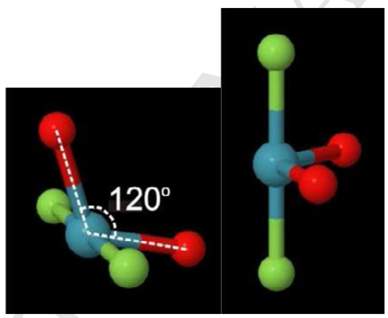
a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: see-saw

9. 

You are given two 3-dimensional views of the same species. Ignore the atom colors. Pick ALL the species that has/have that shape. There may be more than one.

a)H_2S b) SO_2 c) BeF_2 d) CO_2 e) BrF_2^- d) H_2O e) $CaCl_2$

	Correct Response: BeF_2, CO_2, BrF_2^- 10.  You are given two 3-dimensional views of the same species. Ignore the atom colors. Pick ALL the species that has/have that shape. There may be more than one. a) BF_3 b) PBr_3 c) CO_3^{2-} d) BrF_3 e) NH_3 f) $FeCl_3$ g) H_3O^+ Correct Response: PBr_3, NH_3, H_3O^+ 11.  You are given two 3-dimensional views of the same species. Ignore the atom colors. Pick ALL the species that has/have that shape. There may be more than one. a) CF_4 b) SCl_4 c) NH_4^+ d) $SnCl_4$ e) AsF_4^- f) SiH_4 g) BrF_4^+ Correct Response: SF_4, BrF_4^+	
Representational Fidelity	1. When I was doing my class assignments on VSEPR theory, there was a direct close connection between my actions/key strokes/mouse clicks and expected changes of the molecular structures. (realism factor)	Witmer & Singer 1998

	2. The visual display quality of the molecular structures distracted me from performing the assigned tasks on VSEPR theory. (realism factor) 3. There were times when the molecules became more real and present for me compared to the real world (realism factor). 4. The molecules seemed like the real molecules to me (realism factor).	
Learners' interaction	1. I was able to examine the molecular structures closely (Control Factor). 2. I was easily able to examine the molecular structures from multiple viewpoints (Control Factor). 3. I was easily able to move and manipulate the molecular structures very easily (Control Factor).	Witmer & Singer 1998
Perceived Ease of Use	1. I found the molecules cumbersome and awkward to use. 2. Learning to interact with the molecules was easy for me. 3. Interacting with the molecules is often frustrating. 4. I found it easy to get the molecules to do what I wanted them to do. 5. The molecular structures were rigid and inflexible to interact with. 6. It is easy for me to remember how to perform tasks. 7. Interacting with molecular structures requires a lot of mental effort. 8. My interaction with the molecular structures was intuitive and easy to figure out.	Davis 1993
Perceived Meaningfulness	1. Using the molecular structures improved the quality of my understanding of VSEPR theory. 2. I felt that I was in control of my own learning about VSEPR theory using the molecular structures. 3. The molecules enabled me to accomplish the task of learning about VSEPR theory easily. 4. The molecules helped me learn about a very important topic, VSEPR theory.	Davis 1993

	5. Using the molecules as an effective way to learn about VSEPR theory. 6. Using the molecules improved my class performance on VSEPR theory. 7. Using the molecules allowed me to learn more about VSEPR theory than would otherwise be possible. 8. Using the molecules enhanced my effectiveness in learning about VSEPR theory. 9. Using the molecules makes it easier to do my school work on VSEPR theory. 10. Overall I found the molecules useful in my school work on VSEPR theory.	
Self-efficacy	1. I am confident I have the ability to learn the material taught about VSEPR theory. 2. I am confident I can do well on exam questions about VSEPR theory. 3. I think I will do as well or better than other students on exam questions about VSEPR theory. 4. I don't think I will be successful on exam questions about VSEPR theory. 5. I am confident that I can understand the topics taught about VSEPR theory. 6. I believe that if I exert enough effort, I will be successful on the exam questions about VSEPR theory. 7. I can characterize a molecule or ion as obeying or disobeying the octet rule. 8. I feel like I don't know a lot about VSEPR theory compared to other students. 9. Compared with other students in this class, I think I have good study habits. 10. Compared with other students in this class, I don't feel like I'm a good student. 11. I am confident I can do well on the exam questions about VSEPR theory. 12. I am confident I can do well on the lab experiment dealing with VSEPR theory. 13. I think I will receive a B or better in Chem 101. 14. I don't think I will get a good grade the exam questions dealing with VSEPR theory.	Witt-Rose (2004)

	15. I am confident that I could explain concepts on VSEPR theory learned in this class to another person.	
Presence	1. I had a sense of being there when I explored the molecular structures.	Slater & Usoh,1994

Highlights

- Science achievements can be improved at the college level using 3D virtual reality.
- We used statistical technique of structural equation modeling to test the model
- 3D virtual environments indirectly support the development of spatial ability
- 3D virtual environments indirectly support the enhancement of self-efficacy levels
- 3D virtual environments indirectly improve the learning of chemistry concept.

Table 1
Demographic Statistics

Variable Groups		N	Percentage
Gender	Female	136	33
	Male	68	67
Age	< 18	4	2
	18 – 21	188	92
	22 -25	9	4
	26 - 30	3	1
Race/ Ethinicity	Caucasian	148	72
	Hispanic	34	17
	Asia/Pacific Islander	15	7
	African American	3	1
	American Indian/Native Alaskan	3	1

Table 2

Results of Measurement Model Analysis

Factors	Model Fit Indices	Factor loadings	Cronbach's Alpha/Omega
Chemistry learning test	Chi-square = 139.037 df =44, p= 0.001 N = 207 Normed chi-square = 3.159 CFI = 0.92 TLI = 0.89 SRMR = 0.05 RMSEA = 0.06	0.41-0.73	0.61/0.71
Spatial Orientation	Chi-square = 222.145 df = 170, p= 0.004 N = 204 Normed chi-square = 1.306 CFI = 0.94 TLI = 0.93 SRMR = 0.04 RMSEA = 0.02	0.54-0.73	0.77/0.89
Representational fidelity	Chi-square = 13.106 df = 2, p= 0.001 N = 204 Normed chi-square = 6.553 CFI = 0.92 TLI = 0.75 SRMR = 0.06 RMSEA = 0.16	0.21 – 0.40	0.49/0.58
Learners' interaction	Chi-square = 197.663 df = 3, p= 0.001 N = 204 Normed chi-square = 65.887 CFI = 1.00 TLI = 1.00 SRMR = 0.00 RMSEA = 0.00	0.65 – 0.77	0.78/0.78

PEU	Chi-square = 62.419 df = 14, p= 0.001 Normed chi-square = 4.4585 N = 204 CFI = 0.94 TLI = 0.91 SRMR = 0.05 RMSEA = 0.13	0.73-0.86	0.89/0.89
PM	Chi-square = 134.276 df = 35, p= 0.001 Normed chi-square = 3.836 N = 204 CFI = 0.96 TLI = 0.95 SRMR = 0.03 RMSEA = 0.11	0.78 – 0.91	0.97/0.97
Self-efficacy	Chi-square = 199.254 df = 65, p= 0.001 Normed chi-square = 3.06 N = 204 CFI = 0.92 TLI = 0.91 SRMR = 0.10 RMSEA = 0.05	0.51 – 0.91	0.93/0.93

Table 3

Descriptive statistics of each variables included in the model

	1	2	3	4	5	6	7	8
Mean	5.09	18.45	4.74	11.56	15.51	30.45	39.30	3.25
SD	1.48	3.89	4.16	4.12	5.54	9.70	9.07	1.26
1	1.00	-	-	-	-	-	-	-
2	0.47**	1.00	-	-	-	-	-	-
3	0.11	0.23**	1.00	-	-	-	-	-
4	0.01	0.17*	0.37**	1.00	-	-	-	-
5	0.42**	0.55**	0.26**	0.18**	1.00	-	-	-
6	0.51**	0.66**	0.25**	0.09	0.62**	1.00	-	-
7	0.18*	0.46**	0.46**	0.29**	0.43**	0.54**	1.00	-
8	0.44**	0.34**	0.14	0.03	0.45**	0.48**	0.21**	1.00

This table presents the means, standard deviation and Pearson r correlation of the variables included in the model.

1 = Representational fidelity 2 = Learners' interaction 3 = Chemistry learning test 4 = Spatial orientation 5= Perceived ease of use 6 = Perceived meaningfulness 7 = Self-efficacy 8 = Presence.

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Figure 1:
Theoretical Model

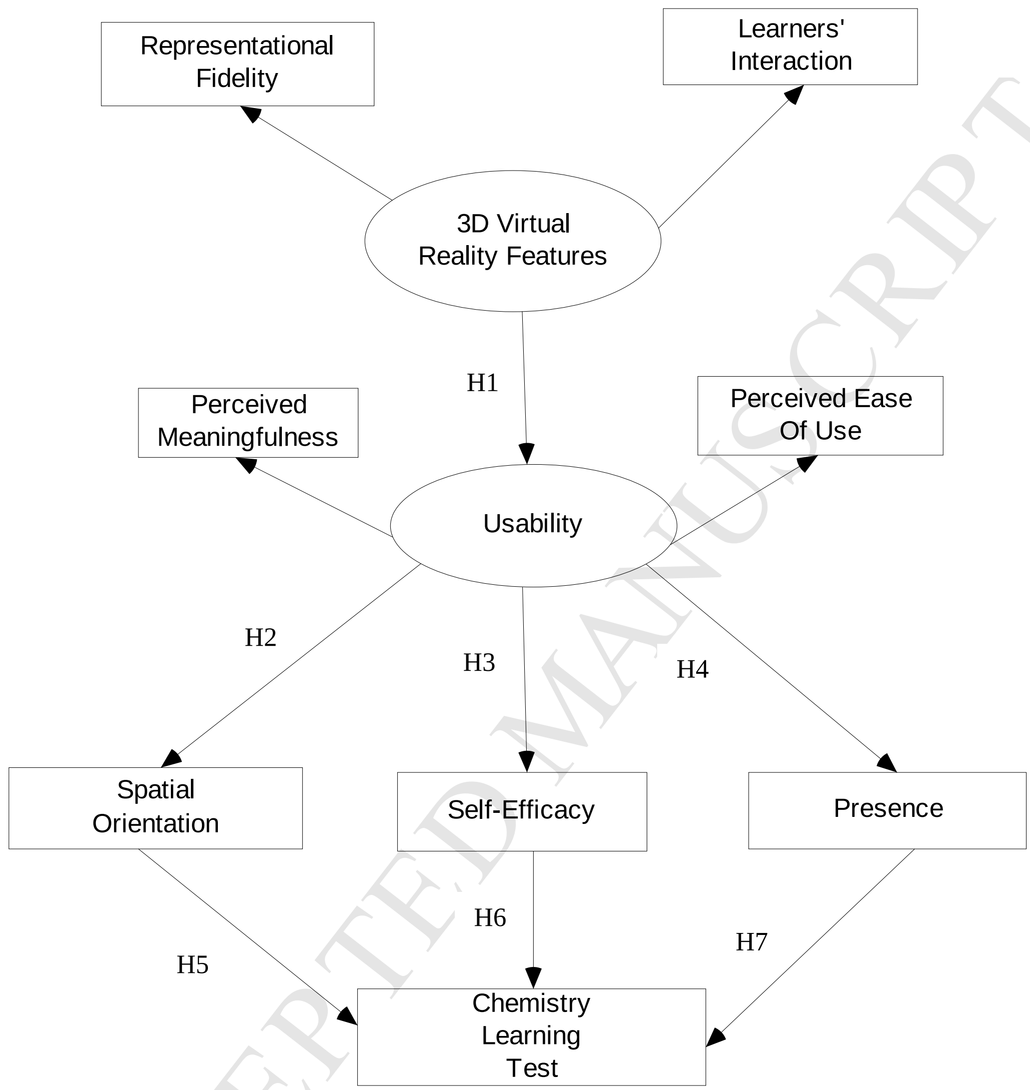


Figure: 2
An example of test question from Purdue Visualization of Rotation test

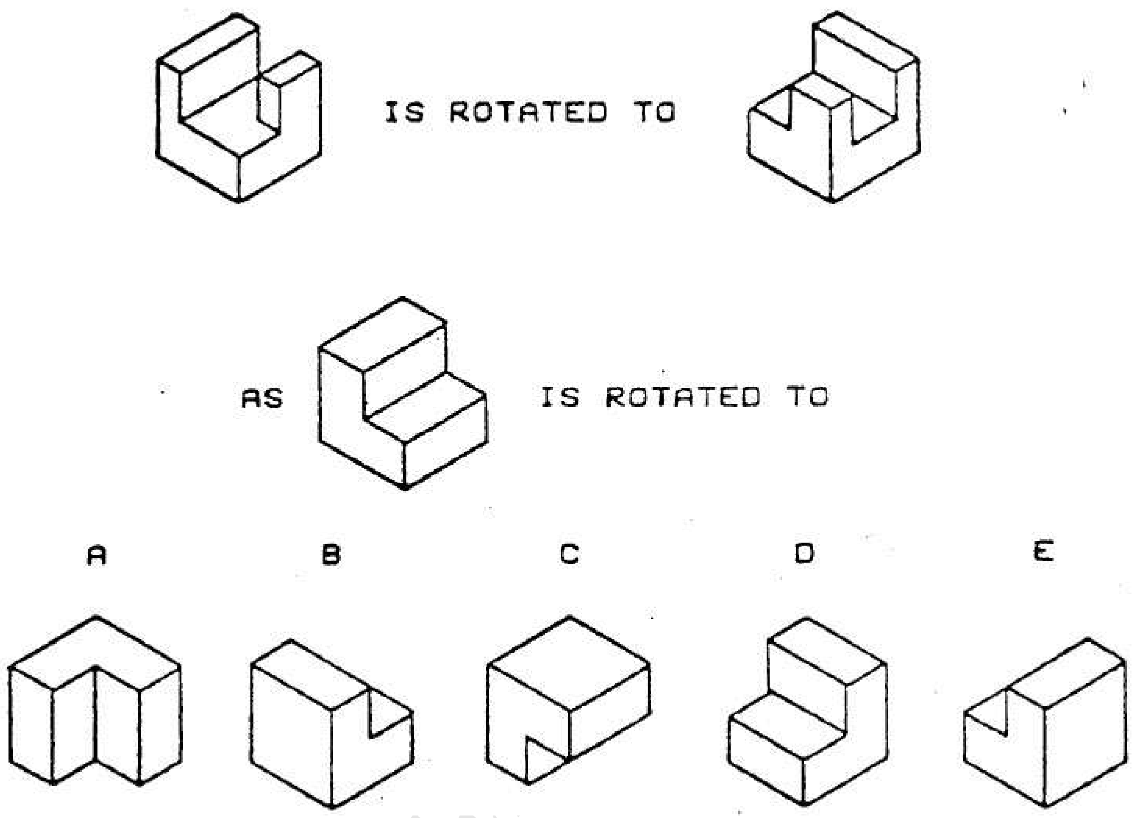
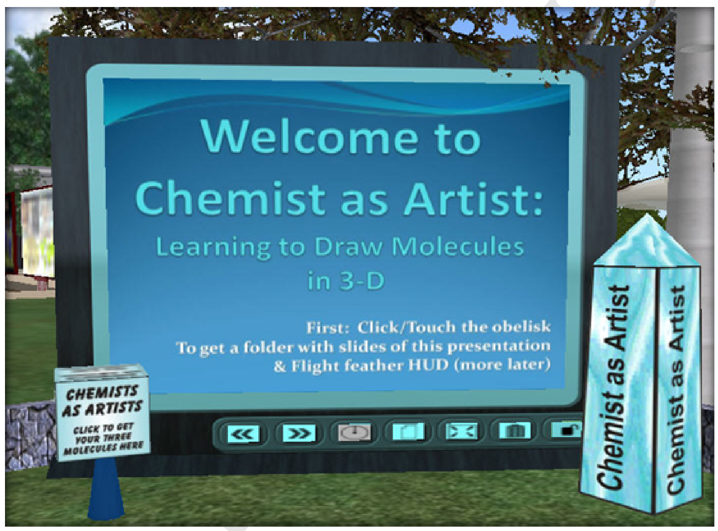


Figure 3:

Activity Stations in Dr K's Chemistry Corner

Intervention 1: Molecule Game

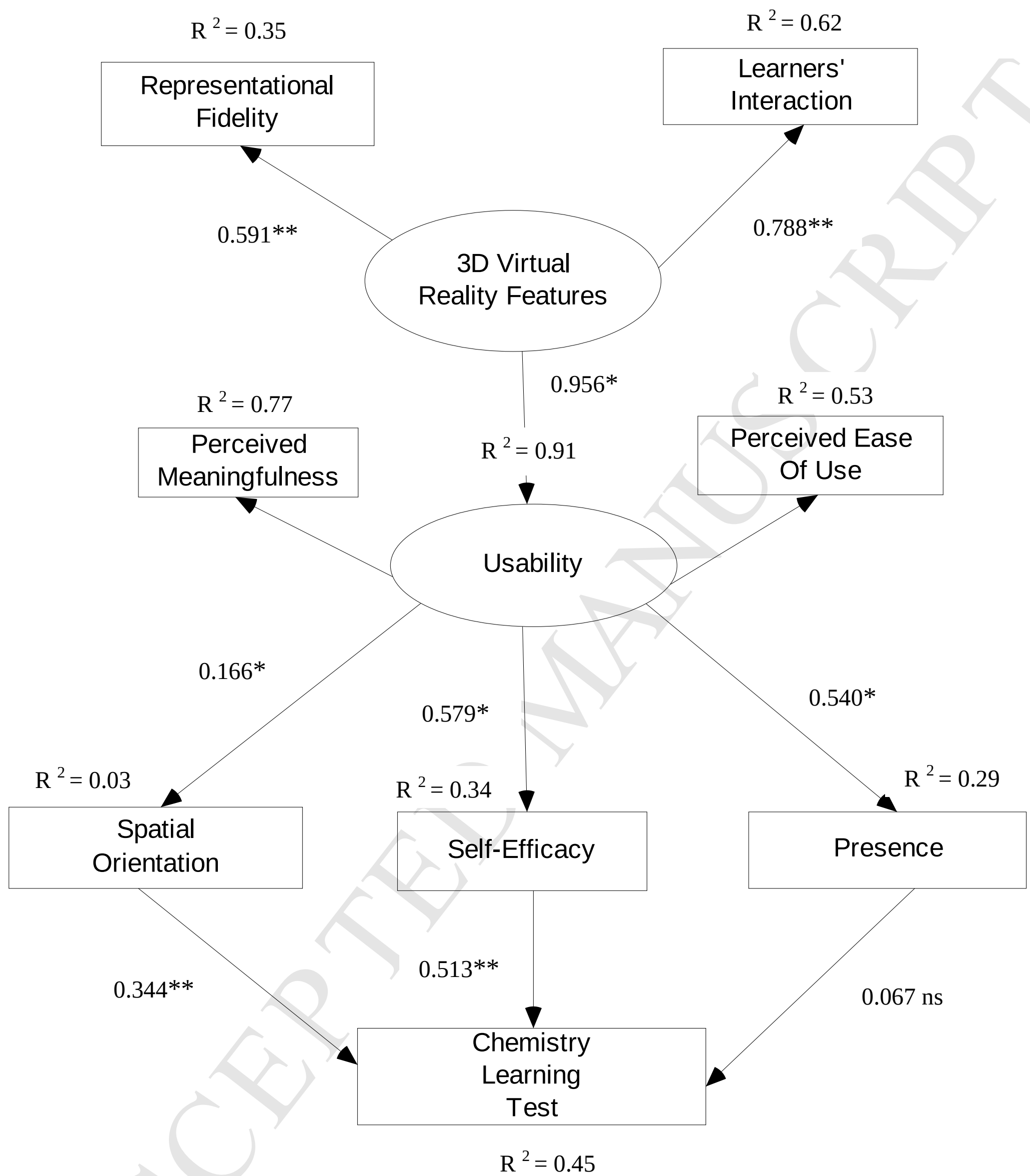
Intervention 2: Chemist as an Artist



Intervention 3: Tower of VSEPR Theory

Figure 4:

Results of Structural Model Analysis



Chi-square = 58.796 df = 31, *p*= 0.001
Normed chi-square = 1.825
CFI= 0.953
TFI = 0.931
RMSEA = 0.06
SRMR = 0.04

*Co-efficient is significant at the 0.05 level (2-tailed).
**. Co-efficient is significant at the 0.01 level (2-tailed).
ns = non-significant